CF-34

- What are the roles of cosmic-ray, gamma-ray, and neutrino experiments for particle physics?
  - What future experiments are needed in these areas and why?
  - Are there areas in which these can have a unique impact?

Questions and Issues

Nature provides sources of VHE (100 GeV-100 TeV) gamma rays

1) How are particles accelerated to such energies?
2) How can we use these particle beams to probe fundamental physics?

The astrophysics and fundamental physics are entangled.

We must understand 1 to get at the fundamental physics.
(or have methods for controlling systematic errors resulting from our lack of understanding of 1)

Scientific Motivation for DPF

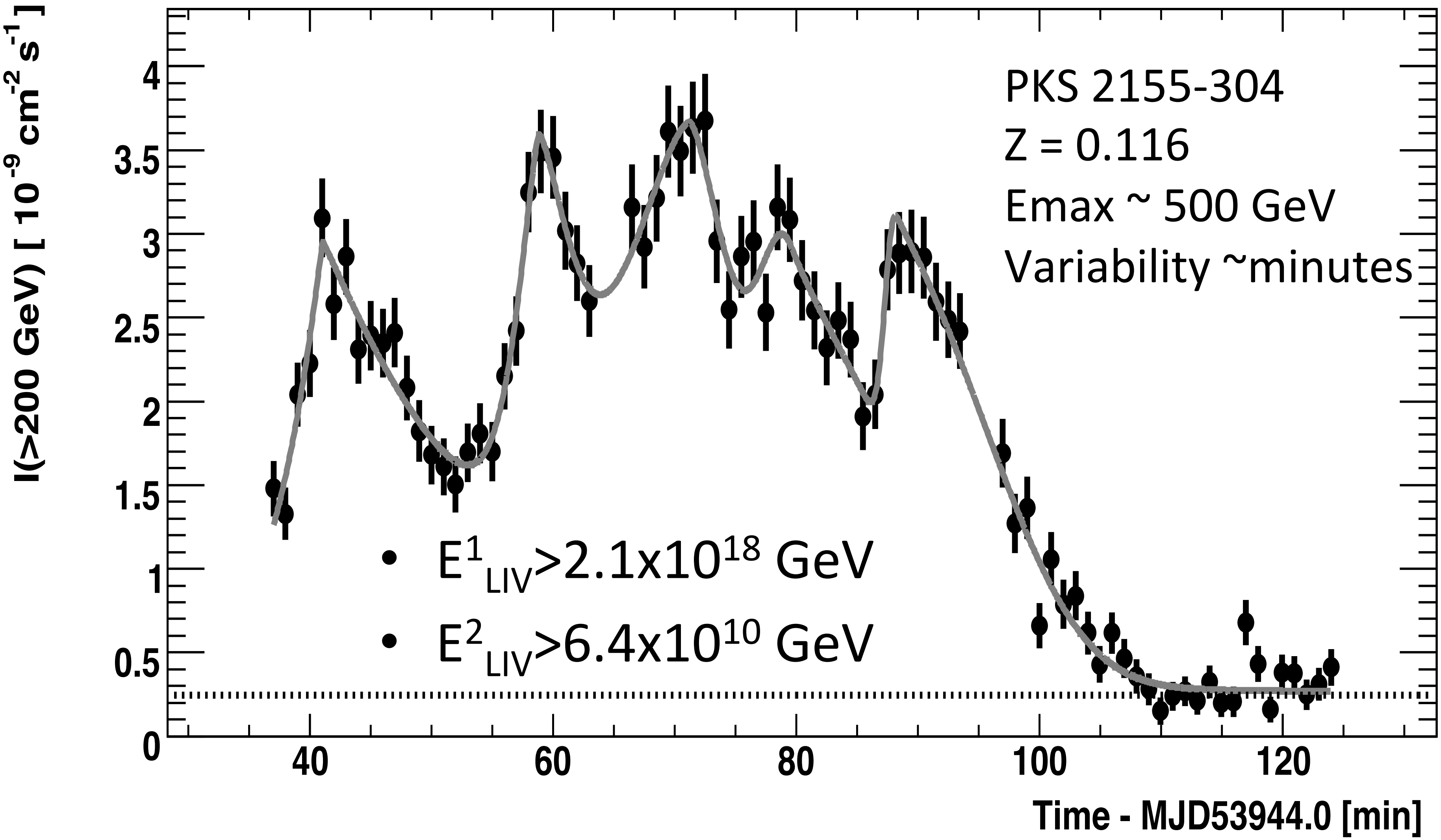
- Indirect WIMP Dark matter (see CF-2 for discussion)
- Non-WIMP Dark Matter
  - Axions
  - ***Q-Balls*** (unique direct detection techniques using CGN experiments)
  - Primordial black holes (*unique sensitivity to final phase of evaporation*)
- Fundamental Symmetries
  - ***Lorentz Invariance*** (window into physics at the Planck scale)
- Cross Sections and new physics
  - ***JEM-EUSO 300 TeV C-M energy of collisions (already hints of non-standard interactions at Auger)***
  - ***High-Energy neutrino cross sections sensitive to extra dimensions***
- Neutrino mass hierarchy
  - Supernova neutrinos
  - Atmospheric neutrinos

Lorentz Invariance Violation

- Vacuum dispersion relation for photons
- Energy dependent speed of light
- Physics at Planck scale
  - Quantum Gravity
  - String Theory
- Can not directly probe this energy scale

$$\frac{\mathrm{v}(p)}{c} = 1 + \zeta_1 \left(\frac{p}{E_{LIV}} \right) + \zeta_2 \left(\frac{p}{E_{LIV}} \right)^2 \qquad \Delta t \approx \frac{1}{\zeta_n} \left(\frac{\Delta E}{E_{LIV}} \right)^n \frac{L}{c}$$

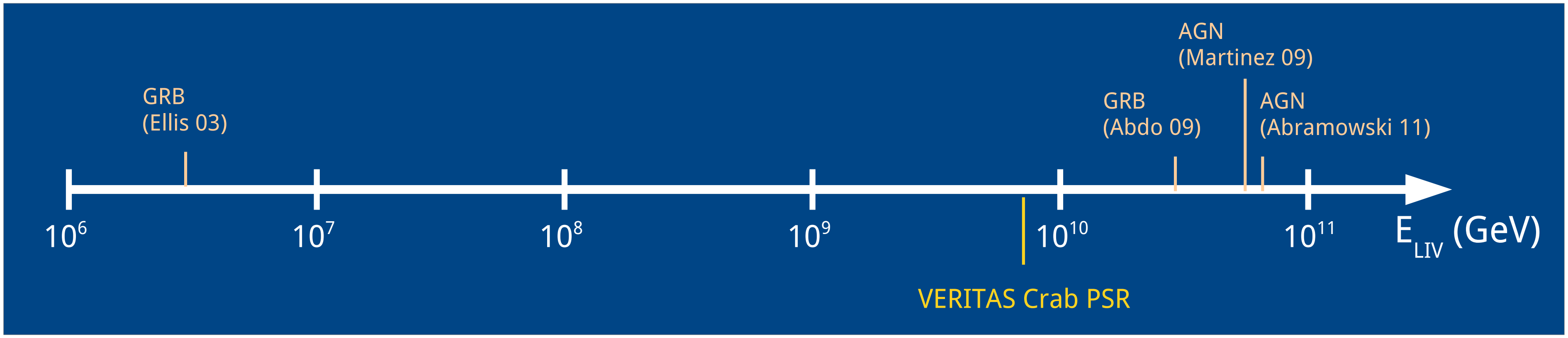
Testing LIV with Active Galaxies



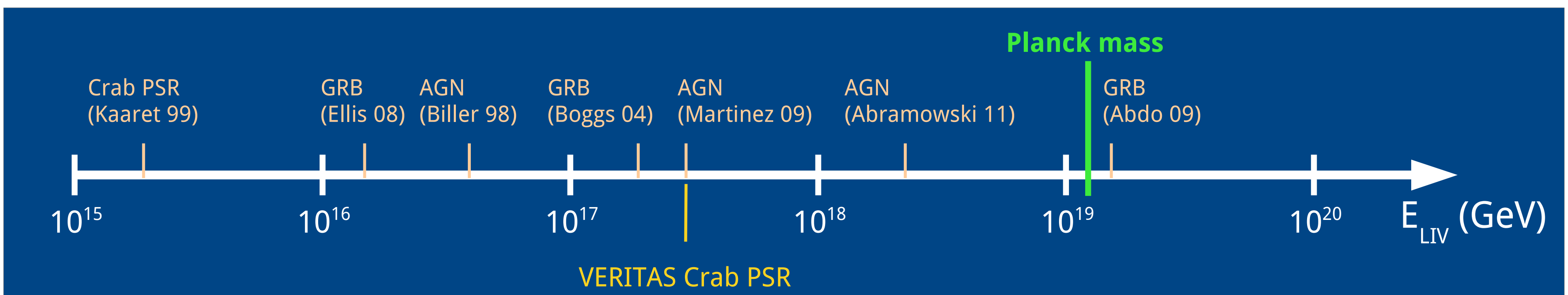
- $E^1_{LIV} > 2.1\times10^{18}$ GeV
- $E^2_{LIV} > 6.4\times10^{10}$ GeV

Current Limits

Quadratic term:



Linear term:



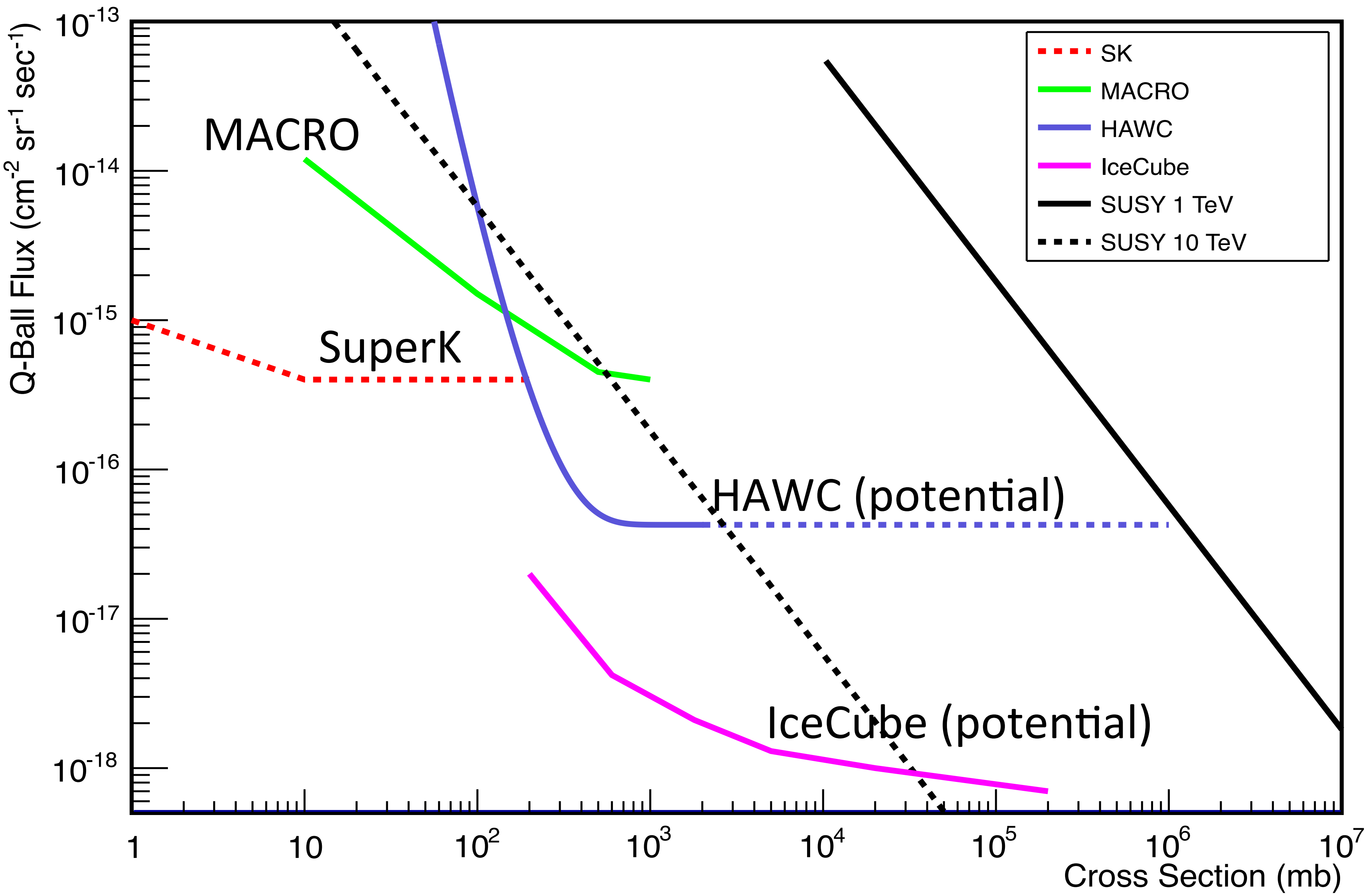
Future Prospects

- CTA 10x sensitivity can probe 1/100 time scale
  - Linear term can reach >10x Planck mass
- Quadratic term is not well constrained
  - High energy more critical than distance
  - >50x improvement with CTA (using known AGN variability)
- Untangling source effects requires different types of sources (GRBs and AGN) at different redshifts

Q-Balls

- Smoking Gun signature of Affleck-Dine baryogenesis
- Explains Baryon asymmetry and dark matter
- Large mass: $10^{\sim 15}$ GeV
- Spectacular signal (~10 GeV/cm in pions)
- Low flux: $<10^{-16} cm^{-2} sr^{-1} s^{-1}$
- Large detectors needed: SuperK, HAWC, IceCube

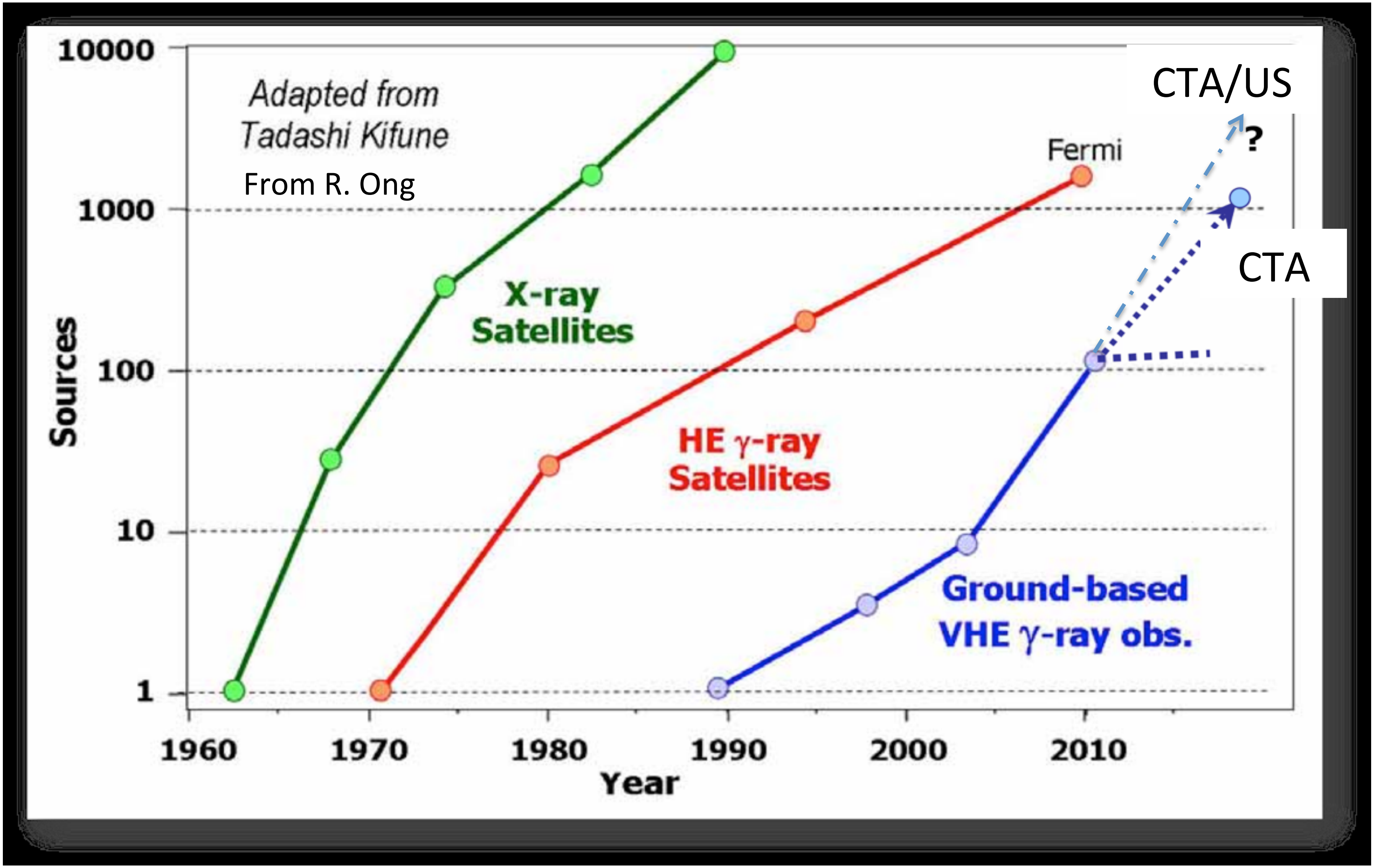
Current and Future Limits



Gamma Rays

- To extract fundamental physics (dark matter, primordial black holes, axion-like particles, Lorentz invariance tests, etc.) We need:
  - Large database of objects with various astrophysical characteristics (distance, energy, local environments)
  - Precision measurements of energy and time evolution across large energy span (multi-wavelength/messenger observations)
  - Combination of all-sky finders and precision TeV instruments
- Instrument needs
  - CTA (VERITAS), HAWC (or nextGen all-sky instrument), Fermi
- CTA improvements
  - 10x sensitivity
  - 1/100 time to detection
  - 5x better angular resolution
  - >10x sources with larger redshift range and larger energy range

Progress in Gamma Rays



Summary

- We are entering an era of precision VHE gamma-ray astrophysics
  - Unprecedented angular and energy resolution
  - Unprecedented sensitivity (1000-fold increase since 1990)
  - Huge energy range (100 MeV – 100 TeV)
  - Will enable understanding of astrophysical processes or control of systematics
- Increased sensitivity
  - Faster resolution of temporal features (LIV)
  - Larger energy range and more distant sources (Axions, LIV)
  - Sensitivity to more distant sources (PBH 10-100x volume increase)
- Extraction of fundamental physics possible with future instruments (operated simultaneously)
  - Fermi, HAWC, VERITAS → CTA